items. Therefore, Applicant respectfully requests the Examiner to enter said response.

If the Examiner has any questions or comments that would speed prosecution of this case, the Examiner is invited to call the undersigned at 219/485-6001.

Respectfully submitted,

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Title: THREE-DIMENSIONAL PERIODIC STRUCTURE, ITS FABRICATION METHOD, AND METHOD OF FABRICATION FILM

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Three-dimensional periodic structure, its fabrication method, and method of fabricating film

Technical Field

The present invention relates to a generic technique concerning a structure having substantially three-dimensionally-periodical refractive index distribution, which is used, for example, as a light wave circuit element, its fabricating method, applied technique, and an applied device.

Background Art

A technique for fabricating a three-dimensional periodic structure having a period of about 1 μm or less in a material has a broad range of possible application in the fields of optical technologies and electronic technologies. However, its fabrication method is not developed yet, and a three-dimensional periodic structure with a period of about 1 μm or less has not been realized up to now. Among techniques which have been examined, the following two are main ones: (1) a method in which holes are formed in three directions by dry etching, as shown in Fig. 54, (E. Yablonovitch, "Photonic band-gap structures", J. Opt. Soc. Am. B, vol. 10, no.2, pp. 283-295, 1993); and (2) a method in which substrates with parallel square rods on them are opposed and bonded to each other, one of the substrates is removed by selective etching, and another substrate is opposed and bonded again to repeat the operation, as shown in Fig. 55, (S. Noda, N. Yamamoto, and A. Sasaki, "New realization method for three-dimensional photonic crystal in optical wavelength region", Jpn. J. Appl. Phys., vol. 35, pp. L909-L912, 1996). Up to now, these two ideas are not realized in the case that the period is about 1 μm or less and the number of periods is five or more.

In the above-mentioned method (1), it is disadvantageous that processing of more than three or four periods is impossible. In the above-mentioned method (2), reproducibility and productivity are low, since it depends on handicraft processes with low controllability such as selective chemical etching and bonding many times.

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The present invention is completed to solve the above-described problems of the conventional techniques, and its object is to provide a three-dimensional structure having a period of about 1 μm or less, to provide parts and devices to which that structure is applied, and to provide their fabrication method.

Disclosure of the Invention

To attain the above-described object, it is necessary to realize a three-dimensionally-periodic structure by a method superior in reliability and reproducibility. For that purpose, to effect ~~is effective~~ such a method, ~~that~~ at least two kinds of materials are laminated sequentially and periodically, and sputter etching is carried out separately from or simultaneously with film formation with regard to at least a part of the laminated layers. This method can fabricate a three-dimensional periodic structure having a period of about 1 μm or less.

Functions

When a three-dimensional periodic structure is constructed by the above-described means, it is possible to realize one having a period of about 1 μm or less, simply and with good reproducibility. Further, into the periodic structure, can be introduced a material of nonlinear optical susceptibility, a light emitting or light amplifying material, an electrooptic material, a transparent object, an electrically-conductive material, or the like. Further, into the periodic structure, can be built a waveguide, resonator, branch, coupler, reflector, semiconductor laser, optical detector, or the like. Accordingly, an applied part or device can be fabricated by a method which is superior in reliability and repeatability. The present invention is generic one in that it originates from a common root and comprehends various developments, which will become obvious from the following embodiments.

Brief Description of Drawings

The above-mentioned and other features and advantages of this invention, and the manner of attaining them, will become more apparent and the invention will be better understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

Fig. 1 is an explanatory view showing one embodiment of the invention;

Fig. 2 is an explanatory view showing a sputtering method;

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of the invention;

Fig. 21 is an explanatory view showing a fabrication mechanism of the invention;

Fig. 22 is a view for explaining characteristics of a three-dimensional periodic structure;

Fig. 23 is an explanatory view showing a Brillouin zone, whose structure is hexagonally symmetric in the xy plane and periodic in the z direction;

Fig. 24 is an explanatory view showing one embodiment of the invention, a circle of the dashed line meaning that a round hole shown by the solid line does not ~~exist in that place where it should exist originally~~;

Fig. 25 is an explanatory view showing one embodiment of the invention;

Fig. 26 is an explanatory view showing one embodiment of the invention;

Fig. 27 is an explanatory view showing one embodiment of the invention;

Fig. 28 is an explanatory view showing one embodiment of the invention;

Fig. 29 is an explanatory view showing one embodiment of the invention;

Fig. 30 is an explanatory view showing one embodiment of the invention;

Fig. 31 is an explanatory view showing one embodiment of the invention;

Fig. 32 is an explanatory view showing one embodiment of the invention;

Fig. 33 is an explanatory view showing one embodiment of the invention;

Fig. 34 is an explanatory view showing one embodiment of the invention;

Fig. 35 is an explanatory view showing one embodiment of the invention;

Fig. 36 is an explanatory view showing one embodiment of the invention;

Fig. 37 is an explanatory view showing selective lamination used in one embodiment of the invention~~, T indicating a top and V indicating a valley~~;

Fig. 38 is an explanatory view showing selective etching used in one embodiment of the invention, by which a profile of the solid line is changed to a shape of the dashed line;

Fig. 39 is an explanatory view showing selective etching used in one embodiment of the invention, by which a profile of the solid line is changed to a shape of the dashed line;

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Fig. 40 is an explanatory view showing one embodiment of the invention;

Fig. 41 is an explanatory view showing one embodiment of the invention;

Fig. 42 is an explanatory view showing one embodiment of the invention;

Fig. 43 is an explanatory view showing one embodiment of the invention, in which ellipses indicate island film metal and are dotted over on a curved surface;

Fig. 44 is an explanatory view showing one embodiment of the invention;

Fig. 45 is an explanatory view showing one embodiment of the invention;

Fig. 46 is an explanatory view showing one embodiment of the invention;

Fig. 47 is an explanatory view showing one embodiment of the invention;

Fig. 48 is an explanatory view showing one embodiment of the invention~~, in which, a method of inserting a functional material F into interface of A and B (i.e., 1 and 2) is the method (b), and a method of making A or B of F is the method (c)~~;

Fig. 49 is an explanatory view showing one embodiment of the invention;

Fig. 50 is an explanatory view showing a method of fabricating one embodiment of the invention;

Fig. 51 is an explanatory view showing one embodiment of the invention;

Fig. 52 is an explanatory view showing one embodiment of the invention;

Fig. 53 is an explanatory view showing one embodiment of the invention;

Fig. 54 is an explanatory view showing a method of fabricating a three-dimensional periodic structure that does not use the present invention; and

Fig. 55 is an explanatory view showing a method of fabricating a three-dimensional periodic structure that does not use the present invention.

Corresponding reference characters indicate corresponding parts throughout the several views. The exemplification set out herein illustrates one preferred embodiment of the invention, in one form, and such exemplification is not to be construed as limiting the scope of the invention in any manner.

(Explanation of the reference numerals)

1	material A (for example, SiO_2);
2	material B (for example, Si);
3	substrate;
4	vacuum chamber;
5	target;
6	matching circuit;

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referred ~~to~~ in the present invention and some which can be applied to the ~~present~~ invention will be described in outline.

Fig. 2 is a schematic view showing an ordinary high frequency sputtering system. Inside a vacuum chamber 4, are arranged a target 5, which is a supply source of source material for thin film, and a substrate 3 opposed to the target 5. The target 5 is connected to a high frequency power source 7 via an impedance matching circuit 6. Into the inside of the vacuum chamber 4, is introduced gas which includes an inert gas (for example, Ar gas) as its main component and is obtained, for example, by adding hydrogen gas to Ar gas. Then, high frequency power is supplied to the target electrode to generate plasma. Since the target 5 is at negative potential on time average (self-bias effect), positively-charged gaseous ions are incident to the target 5, while having high energy (solid line arrows), to scatter the target material. The scattered material particles arrive at and adhere to the substrate 3 (dashed line arrows) to form a film on the substrate.

Fig. 3 shows an outline of a bias sputtering system. In comparison with the system of Fig. 2, this is added with a substrate electrode 8, which is connected to a high frequency power source 7 through a matching circuit. By supplying high frequency power to the substrate electrode 8, gaseous ions are made to be incident to the surface of the substrate 3 (solid line arrows) similarly to the case of the target 5, and thus, it is possible to scatter particles from the surface of the substrate 3. By varying the high frequency power to be supplied, the kind and pressure of the gas, the shape of the substrate electrode, and the like, it is possible to control quantity and energy of the impacting ions and effect of the sputtering.

Conventionally, the bias sputtering method has been utilized as a thin film formation process (metallization) for forming electrodes and wiring in LSI. For example, as shown in Fig. 5, it is utilized for embedding metal film wiring 10 in a dielectric 9 to flatten an upper surface, or, as shown in Fig. 4, for filling up a space between two wires 10 not to produce a hollow portion. On the other hand, it is entirely novel technique to employ bias sputtering or sputter etching for shaping the film described below.

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element having strong selectivity for wavelength and direction (wave number) of incident light. By using, for example, a material having electrooptic effect as a component of PBS, PBS can be varied in its filter property by applying external voltage. Thus, it is possible to electrically program a response characteristic of the photodetector.

[Embodiment 13]

By periodically laminating two or more kinds of transparent materials having common periodic recessed or projecting portions on a substrate having two-dimensionally periodic recessed or projecting portions with orthogonal x- and y-axes being as axes of symmetry as shown in Fig. 18, that three-dimensional structure functions as a biaxial anisotropic artificial medium having an effective optical dielectric tensor:

$$\bar{\varepsilon} = \begin{bmatrix} \varepsilon_{xx} & 0 & 0 \\ 0 & \varepsilon_{yy} & 0 \\ 0 & 0 & \varepsilon_{zz} \end{bmatrix}$$

in a general wavelength region except for a cutoff frequency region. According to suitable design, a medium constant within some range can be continuously realized, differently from natural material. Further, it has a property that very large anisotropy can be realized owing to strong dispersion appearing in the neighborhood of the cutoff region.

Industrial Applicability

As described above, according to the method of Claim 2, 4, or 6, it is possible to industrially produce an extremely fine three-dimensional periodic structure by effectively utilizing shaping effects of the technique that employs sputter etching by itself or at the same time with film formation. Thus, it is possible to realize photonic bandgap effect.

According to the above ~~Claim 9~~, by developing the above-mentioned technique furthermore, it is possible to periodically provide material with nonlinear optical

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susceptibility, electrooptic material, transparent material, conductive material, or the like, inside the three-dimensional periodic structure. Thus, a great variety of electronic functions and optical functions can be realized.

According to the above ~~Claim 10~~, it is possible to periodically provide light emitting or light amplifying material inside a three-dimensional periodic structure, and a high efficient optical active element can be realized.

According to the above ~~Claim 11~~, it is possible to integrate functional parts such as a waveguide, resonator, branch, coupler, reflector, optical detector, or the like, inside a three-dimensional periodic structure in which at least two kinds of film transparent material having periodic recessed and projecting pattern is nearly periodically laminated sequentially, i.e., inside an artificial medium having cutoff characteristic for a certain light wavelength region. Thus, it is possible to effectively utilize the advantage of the non-radiative characteristic.

~~According to Claim 12, i~~It is possible to provide a semiconductor laser inside a three-dimensional periodic structure, and thus high efficient laser action without loss of spontaneously emitted light can be realized.

~~According to Claim 13, i~~It is possible to realize a structure in which, on a substrate having two-dimensionally periodic recessed and projecting patterns with the axes of symmetry of orthogonal x- and y-axes on the substrate, at least two kinds of film transparent materials having common periodic recessed and projecting patterns are laminated sequentially and periodically. Accordingly, it is possible to realize optical biaxial anisotropy expressed by a diagonal dielectric tensor of any values.

While this invention has been described as having a preferred design, the present invention can be further modified within the spirit and scope of this disclosure. This application is therefore intended to cover any variations, uses, or adaptations of the invention using its general principles. Further, this application is intended to cover such departures from the present disclosure as come within known or customary practice in the art to which this invention pertains and which fall within the limits of the appended claims.